A POSSIBLE TWO-COMPONENT STRUCTURE OF THE NON-PERTURBATIVE POMERON

Pierre GAURON and Basarab NICOLESCU

LPNHE*- LPTPE, Université Pierre et Marie Curie,
4, Place Jussieu, 75252 Paris Cedex 05, France
gauron@in2p3.fr, nicolesc@lpnp66.in2p3.fr

Abstract

We propose a QCD-inspired two-component Pomeron form which gives an excellent description of the pp, πp, Kp, γp and $\gamma\gamma$ total cross-sections. Our fit has a better χ^2/dof for a smaller number of parameters as compared with the PDG fit. Our 2-Pomeron form is fully compatible with weak Regge exchange-degeneracy, universality, Regge factorization and the generalized vector dominance model.

LPNHE 00-02 April 2000

*Unité de Recherche des Universités Paris 6 et Paris 7, Associée au CNRS

40 years after its introduction [1] and in spite of very important advances in QCD, the Pomeron remains an open problem. In particular, the non-perturbative structure of the Pomeron is still controversial.

The most popular model of the non-perturbative Pomeron is, of course, the Donnachie-Landshoff (DL) model [2]. The total cross-sections for pp and $\bar{p}p$ scattering are parametrized in terms of five parameters :

$$\sigma_{pp} = X_{pp} s^{\varepsilon} + Y_{pp} s^{-\eta} \tag{1}$$

$$\sigma_{\bar{p}p} = X_{pp} s^{\varepsilon} + Y_{\bar{p}p} s^{-\eta} \tag{2}$$

where

$$\varepsilon = \alpha_P(0) - 1 \tag{3}$$

and

$$\eta = 1 - \alpha_R(0)\ ; \tag{4}$$

$\alpha_P(0)$ is the Pomeron-intercept, $\alpha_R(0)$ is the effective non-leading exchange-degenerate Regge intercept and X, Y the corresponding Regge residues. An overall scale factor $s_0 = 1$ GeV^2 is implicitely present in eqs. (1)-(2). The key-parameters ε and $\alpha_R(0)$ have the following values :

$$\varepsilon = 0.0808 \tag{5}$$

and

$$\alpha_R(0) = 0.5475. \tag{6}$$

The pp data are well reproduced. It was therefore tempting to use the DL form to the simultaneous study of all existing total cross-sections. It is precisely what was done by PDG in the last edition of the "Review of Particle Physics" [3], [4].

The total cross-sections σ are parametrized in refs. 3 and 4 in the variant of a non-exchange-degenerate DL form :

$$\sigma_{AB} = X_{AB} s^{\varepsilon} + Y_{1AB} s^{-\eta_1} - Y_{2AB} s^{-\eta_2}, \tag{7}$$

$$\sigma_{\bar{A}B} = X_{AB} s^{\varepsilon} + Y_{1AB} s^{-\eta_1} + Y_{2AB} s^{-\eta_2}, \tag{8}$$

where

$$\eta_1 = 1 - \alpha_{R_+}(0), \quad \eta_2 = 1 - \alpha_{R_-}(0), \tag{9}$$

$\alpha_{R_+}(0)$ and $\alpha_{R_-}(0)$ being the Regge intercepts of the non-leading Regge trajectory R_+ in the even-under-crossing amplitude and R_- in the odd-under-crossing amplitude respectively. X, Y_1, Y_2 are the corresponding Regge

residues. There are 16 parameters for fitting 271 experimental points involving 8 reactions : $\bar{p}p$, pp, $\pi^{\pm}p$, $K^{\pm}p$, γp and $\gamma\gamma$. The overall χ^2 is excellent : $\chi^2/dof = 0.93$[1]. The key-parameter ε has now the value 0.0900.

The problem with the form of refs. 3 and 4 is the bad violation of the weak exchange-degeneracy (i.e. $\alpha_{R_+}(0) = \alpha_{R_-}(0)$), namely

$$\alpha_{R_+}(0) - \alpha_{R_-}(0) \simeq 0.2.$$

However, the *masses of the resonances*, as published in the "Review of Particle Physics" [5], clearly indicate that the weak exchange-degeneracy is respected. As seen from fig. 1a) the 10 resonances belonging to the 4 different $I^G(J^{PC})$ families $\rho - \omega - f_2 - a_2$ are compatible with a *unique* linear exchange-degenerate Regge trajectory

$$\alpha(t) = \alpha(0) + \alpha' t \tag{10}$$

with

$$\alpha(0) = 0.48 \tag{11}$$

and

$$\alpha' = 0.88\ (GeV/c)^{-2}. \tag{12}$$

The numerical values (11)-(12) are extracted just by plugging in (10) the masses and the spins of $\rho_1(770)$ and $\rho_3(1690)$ resonances.

Remarkably enough, the *same* $\alpha(0)$ value (11) is compatible with the $\Delta\sigma$ data for the total cross-section differences

$$\Delta\sigma_{AB} \equiv \sigma_{\bar{A}B} - \sigma_{AB} = 2Y_{2AB}s^{\alpha_{R_-}(0)-1} \tag{13}$$

or

$$\ln\,[s\Delta\sigma_{AB}] = \ln\,(2Y_{2AB}) + \alpha_{R_-}(0) \ln\, s. \tag{14}$$

The $\Delta\sigma$ data for pp, Kp and πp and $\sqrt{s} \gtrsim 6$ GeV [6] shown in the log-log plot of fig. 1b) are all compatible with the straight lines of eq. 14 , the slopes of which are precisely given by the $\alpha_{R_-}(0)$ value of eq. (11).

These indications in favour of the weak exchange-degeneracy, coming both from the resonance and scattering region, is too striking to be a mere coincidence. One can therefore wonder if something is inadequate in the parametrization (7-8).

A first problem can come from the fact that the ratio $\rho(s, t = 0) = \mathrm{Re}F(s, t = 0)/\mathrm{Im}F(s, t = 0)$ has been included into the PDG fit together

[1] A bigger value $\chi^2/dof = 1.02$, corresponding to 383 experimental points and $\varepsilon = 0.0933$, is quoted in table 1 of ref. 4 because real parts are also included in the respective fits (see text for a discussion of this option).

with the total cross-sections. As it is known, the determination of this ρ parameter is semi-theoretical : its value is obtained through an extrapolation of the elastic amplitude to t=0 using a theoretical model. The result is very sensitive to these theoretical assumptions (see, for example, [7]). If we try to redo the minimization using the total cross-sections only, the violation of the weak Regge exchange-degeneracy persists, as already noted in [8]. In the following we will minimize with different analytic forms but using the total cross-sections only.

An important problem may come from the form of the Pomeron. The non-perturbative Pomeron is certainly much more complex than a simple pole, which violates the unitarity. It surely includes cuts associated with multiexchanges which restore unitarity. We do not know the exact form of these complicate singularities. But we can try to mimic them by a 2-component Pomeron, a Pomeron built from two Regge singularities.

The perturbative Pomeron has also a complex form. The BFKL Pomeron is not a simple pole but rather a complicate cut or an accumulation of poles close to $J = 1$. Also, very recently, detailed calculations in the perturbative QCD indicate, in fact, the existence of a 2-component Pomeron. Namely, in LLA, beside the BFKL Pomeron associated with 2-gluon exchange and corresponding to an intercept $\alpha_p^{2g}(0) > 1$, one finds a new Pomeron associated with the 3-gluon exchange with $C = +1$ and corresponding to an intercept $\alpha_p^{3g}(0) = 1$; the 3-gluon Pomeron is exchange-degenerate with the 3-gluon $C = -1$ Odderon [9].

Inspired by these considerations, we explore in this paper the possibility of a 2-component Pomeron in the non-perturbative sector, namely a Pomeron built from two poles. We propose the new analytic forms for the total cross-sections :

$$\begin{aligned}
\sigma_{pp} &= Z_{pp} + X s^{\varepsilon} + (Y_1^{pp} - Y_2^{pp}) s^{\alpha(0)-1} \\
\sigma_{\bar{p}p} &= Z_{pp} + X s^{\varepsilon} + (Y_1^{pp} + Y_2^{pp}) s^{\alpha(0)-1} \\
\sigma_{\pi^+p} &= Z_{\pi p} + X s^{\varepsilon} + (Y_1^{\pi p} - Y_2^{\pi p}) s^{\alpha(0)-1} \\
\sigma_{\pi^-p} &= Z_{\pi p} + X s^{\varepsilon} + (Y_1^{\pi p} + Y_2^{\pi p}) s^{\alpha(0)-1} \\
\sigma_{K^+p} &= Z_{Kp} + X s^{\varepsilon} + (Y_1^{Kp} - Y_2^{Kp}) s^{\alpha(0)-1} \\
\sigma_{K^-p} &= Z_{Kp} + X s^{\varepsilon} + (Y_1^{Kp} + Y_2^{Kp}) s^{\alpha(0)-1} \\
\sigma_{\gamma p} &= \delta Z_{pp} + \delta X s^{\varepsilon} + Y_1^{\gamma p} s^{\alpha(0)-1} \\
\sigma_{\gamma\gamma} &= \delta^2 Z_{pp} + \delta^2 X s^{\varepsilon} + Y_1^{\gamma\gamma} s^{\alpha(0)-1}
\end{aligned} \tag{15}$$

where $\alpha(0)$ is *fixed* to the value $\alpha(0) = 0.48$ as given by resonance masses and a scale factor $s_0 = 1$ GeV^2 is implicitely supposed.

The Pomeron in eqs. (15) has 2 components : the X-component corresponds to a Regge intercept bigger than 1 ($\varepsilon > 0$) and the Z-component

corresponds to an intercept exactly localised at 1. We suppose that the X-component is fully universal (its coupling is the same in all hadron-hadron reactions, as well as the energy behaviour s^ε), while the Z-component is not fully universal. It is tempting to interpret the X-component as the gluonic component of the non-perturbative Pomeron and the Z-component as its flavour-dependent non-perturbative component. It is interesting to note that the possibility of a fully universal Pomeron was already considered in literature [10].

Of course, there is no double counting. In the framework of the S-matrix Theory [11], there are 2 solutions of the Reggeon calculus : a critical Pomeron with intercept equal to 1, leading asymptotically to a $(\ln s)^\eta (\eta < 2)$ behaviour of the total cross-sections, and a supercritical Pomeron with intercept higher than 1, connected, at asymptotic energies, to the Froissart $\ln^2 s$ behaviour of the total cross-sections. In other words, the X and Z components correspond to 2 different Regge singularities.

Both components are supposed to obey the Regge factorization property. This is realized via the δ-parameter in eqs. (15) for the pp, γp and$\gamma\gamma$ processes.

Finally, the secondary Regge pole of intercept $\alpha(0)$ corresponds to an exchange-degenerate trajectory, in agreement with our previous discussion.

The forms (15) involve n=14 parameters (to be compared with the PDG value n=16). The values of the parameters in eq. (15) are given in table 1. The corresponding χ^2 value is excellent : $\chi^2/dof = 0.86$ to be compared with the PDG value $\chi^2/dof = 0.93$. The quality of the fit is illustrated in fig. 2.

The value $\varepsilon = 0.132$ (see table 1) is certainly bigger than the DL value $\varepsilon = 0.081$ or the PDG value $\varepsilon = 0.093$ and it appears as being in between the effective Pomeron intercept value 1.1 and the bare Pomeron intercept value 1.2 [12]. However a direct comparison of different ε values is not yet significative : all the existing data other than σ have first to be refitted by using a 2-component Pomeron amplitude.

Note that the residue of the non-leading Regge trajectory $Y_1^{\gamma\gamma}$, numerically close to 0, is not well determined : its weight in the minimization is negligible due to the low precision of the low energy $\gamma\gamma$ data.

Let us also note that the value $0.303 \cdot 10^{-2}$ of the δ-parameter is perfectly compatible with the generalized vector-dominance model [13].

It is interesting to explore the relative importance of X and Z components in σ, by plotting the ratio R (see fig. 3)

$$R = \frac{X s^\varepsilon}{Z}. \tag{16}$$

It can be seen from fig. 3 that the X-component acts like an asymptotic component. However the asymptoticity is clearly delayed : X dominates over the Z component only in the TeV region. The only exception is the Kp scattering, where the asymptoticity occurs already in the ISR region of energies.

By using the analytic forms (15) and the values of the parameters given in table 1, one can make detailed predictions for σ at high energies, in particular in the RHIC, LHC and cosmic-rays regions of energies - see table 2. However, one should not consider too seriously such predictions : unitarization will certainly introduce important corrections at high energies. The X-component, as the DL Pomeron, violates unitarity.

In conclusion, we propose a QCD-inspired analytic form of the Pomeron, a 2-pole Pomeron form, which gives an excellent fit to the pp, πp, Kp, γp and $\gamma\gamma$ total cross-sections. Compared to the PDG fit with a simple Pomeron-pole, our fit has a better χ^2/dof with a smaller number of parameters. This 2-pole Pomeron form has the advantage to be fully compatible with the weak Regge exchange-degeneracy , universality, Regge factorization and the generalized vector dominance model.

The theoretical and phenomenological implications of the 2-component Pomeron are important and therefore they should be explored in the future in a detailed way.

Acknowledgements. We thank Prof. Vladimir Ezhela for kindly putting to our disposal the PDG data and for very fruitful discussions.We also thank Prof. Alphonse Capella for useful remarks.

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ε	$\delta, 10^{-2}$	X	Z_{pp}	$Z_{\pi p}$	Z_{Kp}
0.132	0.303	7.572	20.251	5.283	2.208

Y_1^{pp}	Y_2^{pp}	$Y_1^{\pi p}$	$Y_2^{\pi p}$	Y_1^{Kp}	Y_2^{Kp}	$Y_1^{\gamma p}$	$Y_1^{\gamma\gamma}$
74.811	29.918	48.972	6.028	34.483	11.935	0.121	$\simeq 0$

Table 1 : The values of the parameters in the analytic forms (15). ε and δ are pure numbers. The rest of the parameters are in mb.

$\sqrt{s}, GeV$	$\sigma_{\bar{p}p}$	σ_{pp}	σ_{π^+p}	σ_{π^-p}	σ_{K^+p}	σ_{K^-p}	$\sigma_{\gamma p}$	$\sigma_{\gamma\gamma}, 10^{-3}$
100	46.8	46.3	31.4	31.3	28.2	28.0	0.140	0.421
200	51.5	51.2	36.3	36.3	33.2	33.1	0.155	0.469
300	54.8	54.7	39.7	39.7	36.6	36.6	0.166	0.501
400	57.5	57.4	42.4	42.4	39.3	39.3	0.174	0.525
500	59.7	59.6	44.6	44.6	41.5	41.5	0.180	0.546
600	61.6	61.5	46.6	46.6	43.5	43.5	0.186	0.564
1800	75.4	75.4	60.4	60.4	57.3	57.3	0.228	0.692
12000	111	111	96.4	96.4	93.3	93.3	0.337	1.02
30000	136	136	121	121	118	118	0.413	1.25

Table 2 : Extrapolation of the analytic forms (15) at high energies. σ are given in mb.

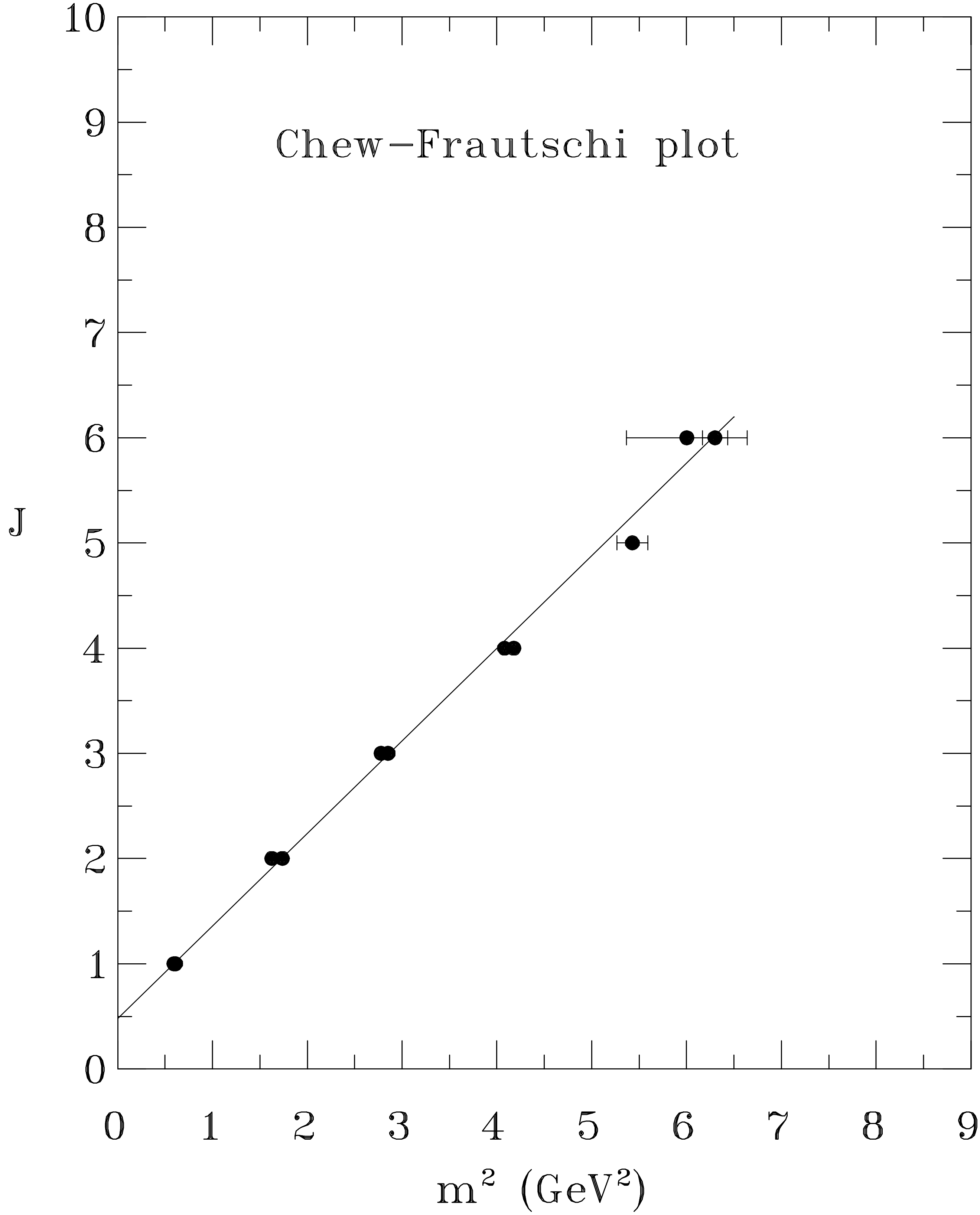

Fig. 1a). The ρ–ω–f_2–a_2 exchange–degenerate Regge trajectory from the resonance masses (Particle Data Group).

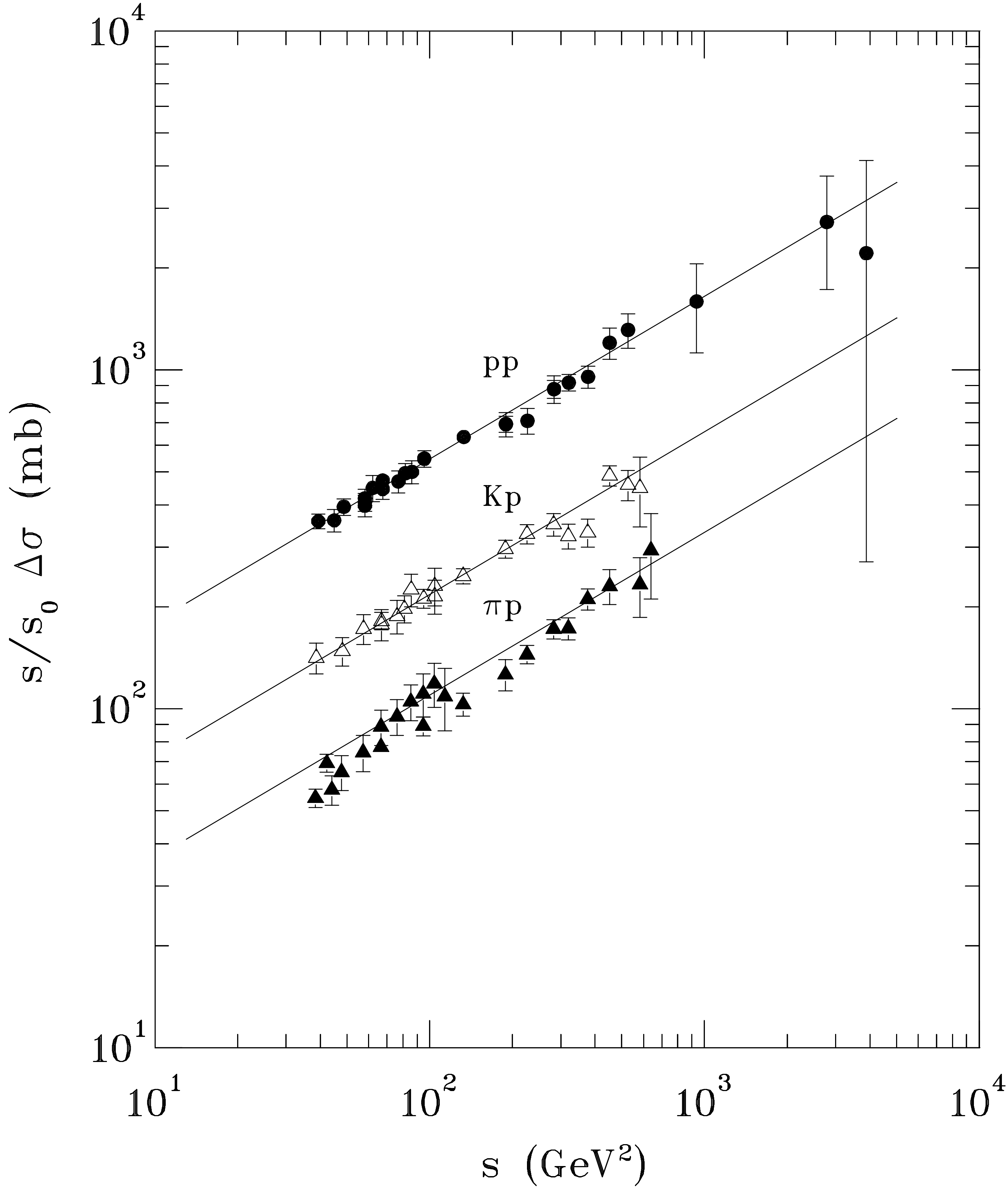

Fig. 1b). The slopes of the $\Delta\sigma$ straight lines are all equal to the Regge intercept of Fig. 1a). Data from ref. 6.

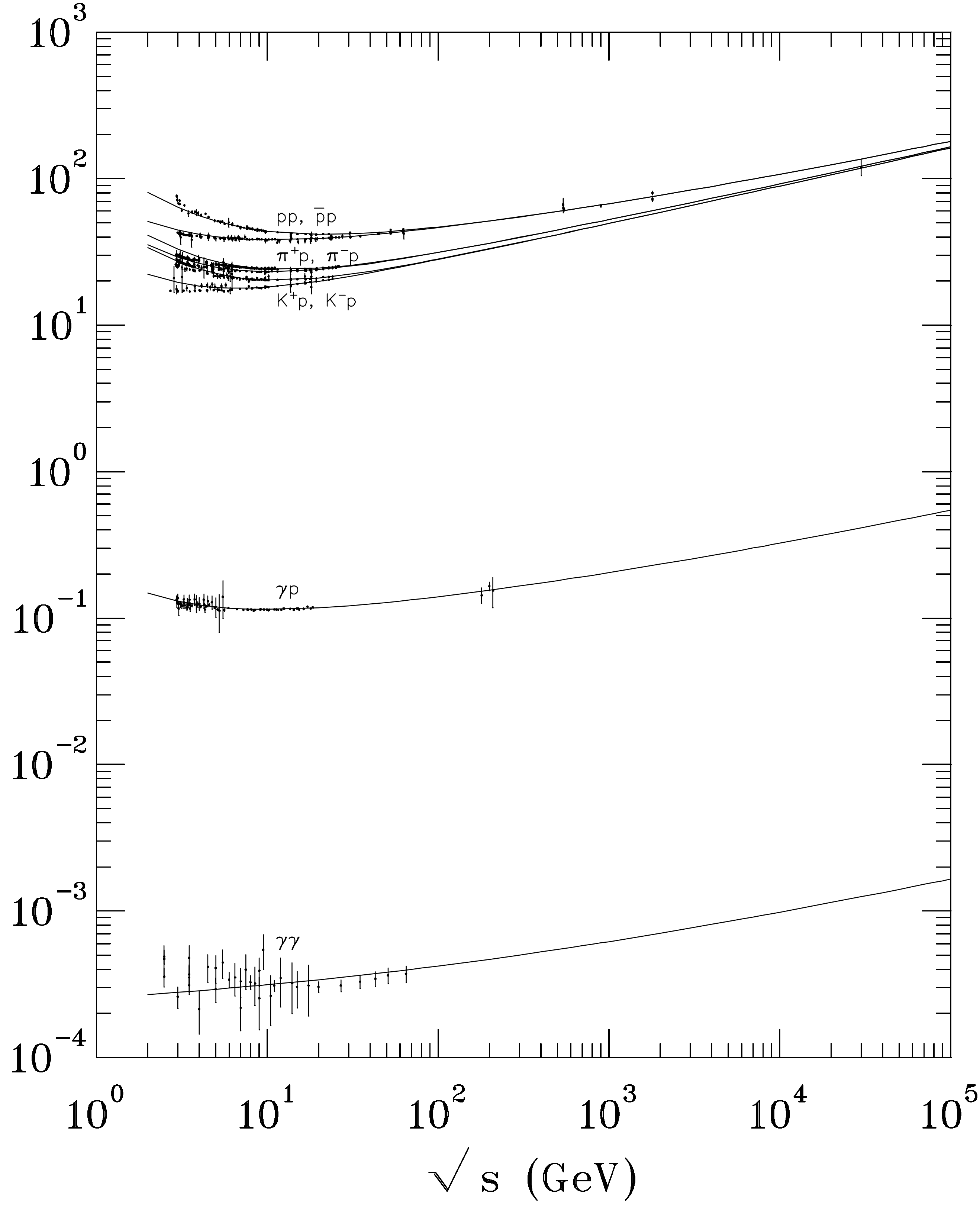

Fig. 2. The description of the total cross-sections through the analytic forms (15). Data from ref. 14.

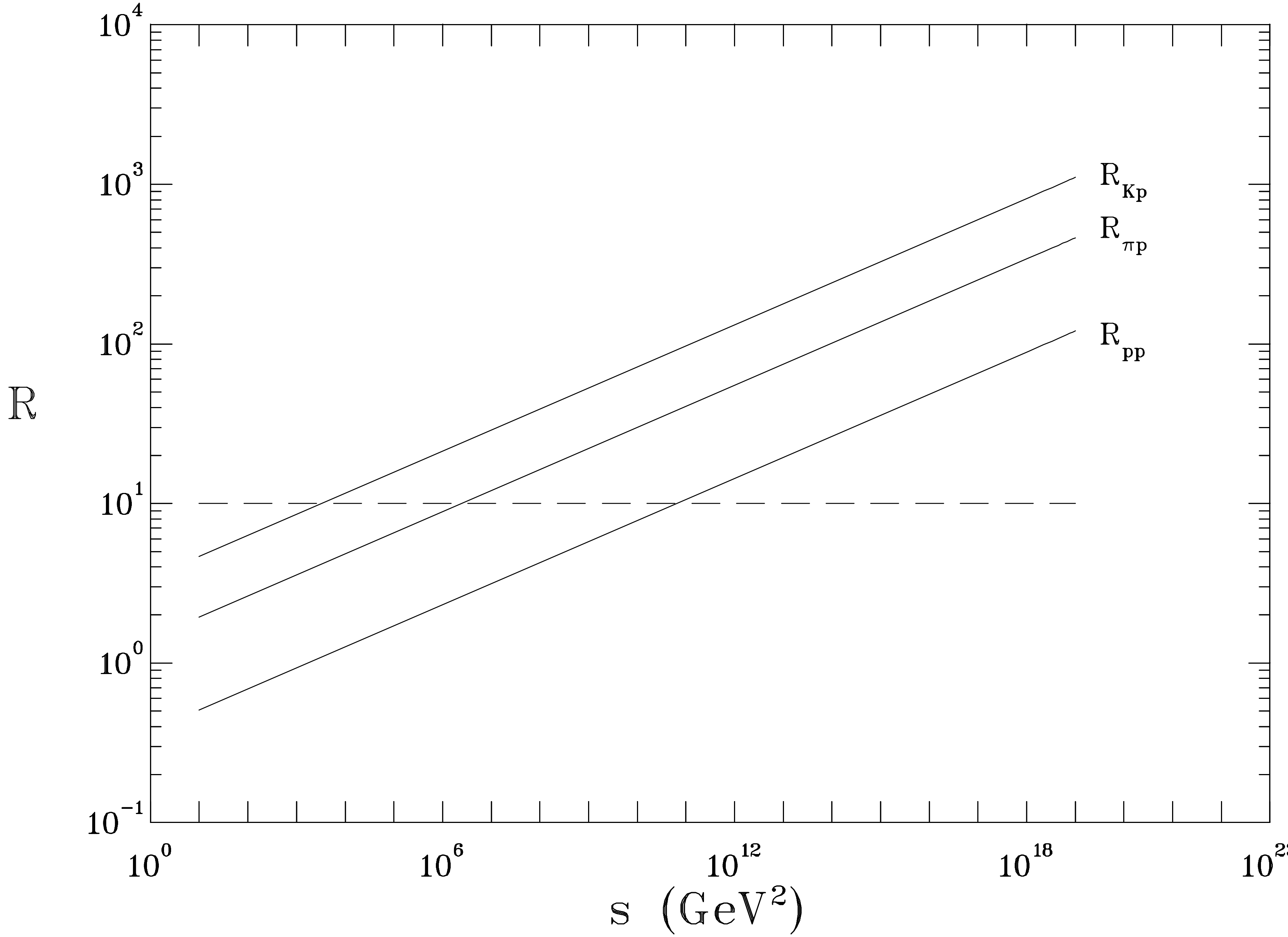

Fig. 3. The ratio $R = (X/s^{\epsilon})/Z$.